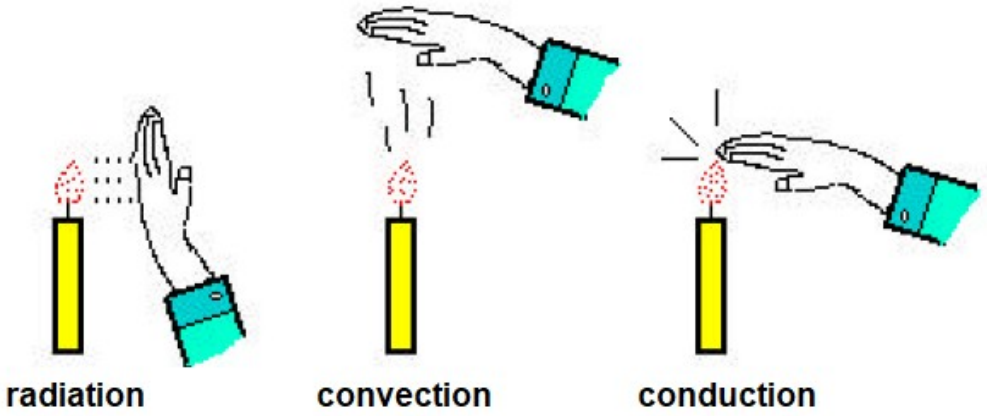
CHAPTER 1: The Basic Boiler

We will define the basic boiler to be able to delve into the different topics with a basic understanding of the boiler itself.

As we have seen in the previous definitions, a boiler is a closed container made of iron and tubes (of special steel for boilers) that is composed of sections where water circulates and sections where hot gases circulate, transferring heat to the water.

According to the laws of physics, this heat is transferred through the metal walls from the hotter gases to the cooler water or steam.

Heat is transferred in three different ways: radiation, convection, and conduction.



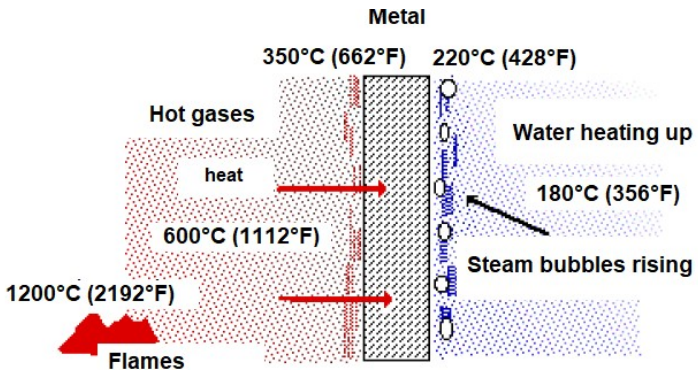
None of the methods of heat transfer exist in isolation in practical life; they are always combined.

Example: While the heat supplied by an electric "radiant" heater (quartz heaters, "rollers," etc.) is predominantly radiant, its heating elements and the surrounding objects are heated by radiation, and these, in turn, heat the surrounding air by conduction.

As the air heats up, it carries the heat to the environment by convection (it circulates as its density decreases), further heating other objects, and so on.

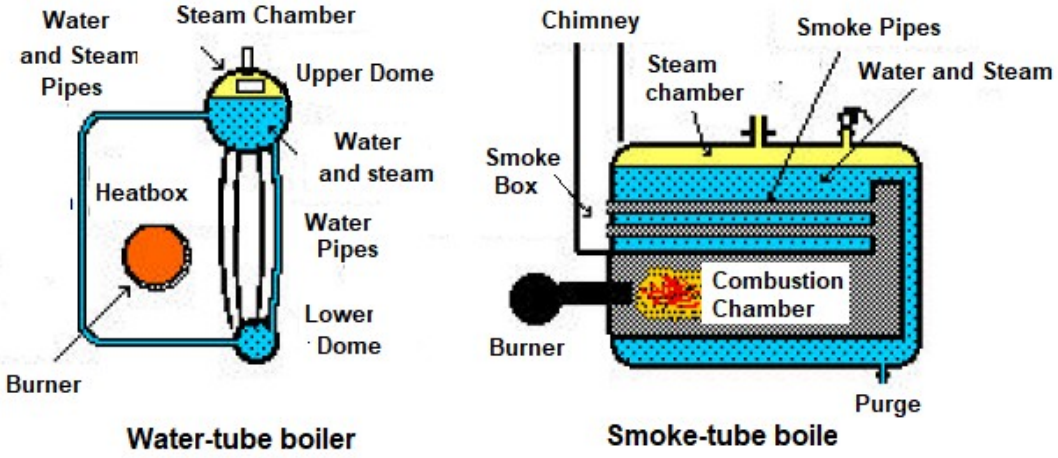
Later we will examine the challenges of transferring this heat through metal between a gas and water (or steam).

Based on the relative position of the gas and water circulation, we find the first major division in boiler construction: water-tube boilers (where water circulates inside the tubes) and fire-tube boilers (where gas circulates inside the tubes).



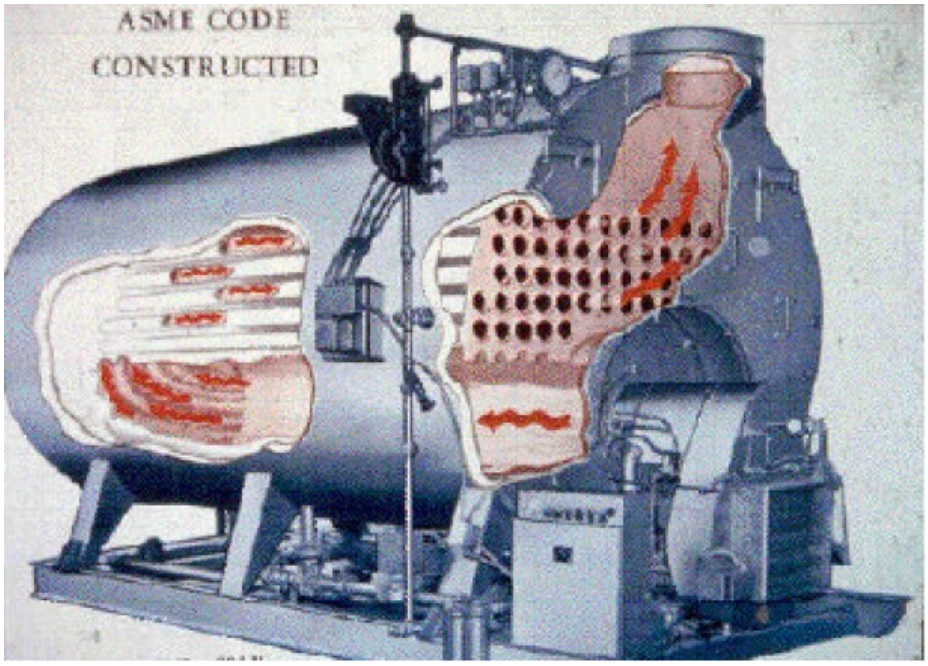
The water-tube boiler consists of vessels (domes and headers) connected by tubes through which water and steam circulate. These surround a combustion chamber, whose heat is transferred to the tubes from the outside.

These boilers were called "explosive-proof" due to their resistance to explosions or accidents. (This is not entirely true under incorrect operating conditions, as they can be prone to combustion chamber explosions.)



The fire-tube boiler (also known as smoke-tube boiler) consists of a vessel through which a cylindrical firebox (usually, although in some cases it may be dome-shaped) and tubes circulate, carrying the combustion gases.

These are the most common type of boiler found in the market, and their working pressure is limited by the size of their body (which subjects the material to high stress).



The most basic boiler we can imagine is the "pressure cooker," used for cooking, but which doesn't fulfill the function of a boiler: producing steam for external use (although its function is similar to a "digester": producing cooking temperatures higher than 100°C (212°F), being the boiling point of water in a regular pot at atmospheric pressure). Because it's subjected to direct heat, we can consider it a very basic boiler to which we must add the missing elements to make it a steam boiler.

In a pressure cooker, we have a certain level of water and a steam chamber (the space that the water vapor occupies when pressure is increased and some of the water evaporates).

This cooker has a maximum working pressure valve, which allows the steam pressure (and therefore the internal temperature) to be raised to a necessary level (which we can consider a pressure regulating and safety valve).

As a maximum pressure safety mechanism, it has a plug that pops open at a higher steam pressure (which we can consider a maximum safety valve or seal).

In a pressure cooker, when the pressure reaches a point where the regulating valve opens, the heat is reduced to decrease steam loss to the atmosphere and prevent the cooker from running out of water.

The goal of a pressure cooker is to achieve a temperature above 100ºC, meaning that the steam pressure is greater than atmospheric pressure.

There are significant differences between this pressure cooker and a boiler. Let's examine them:

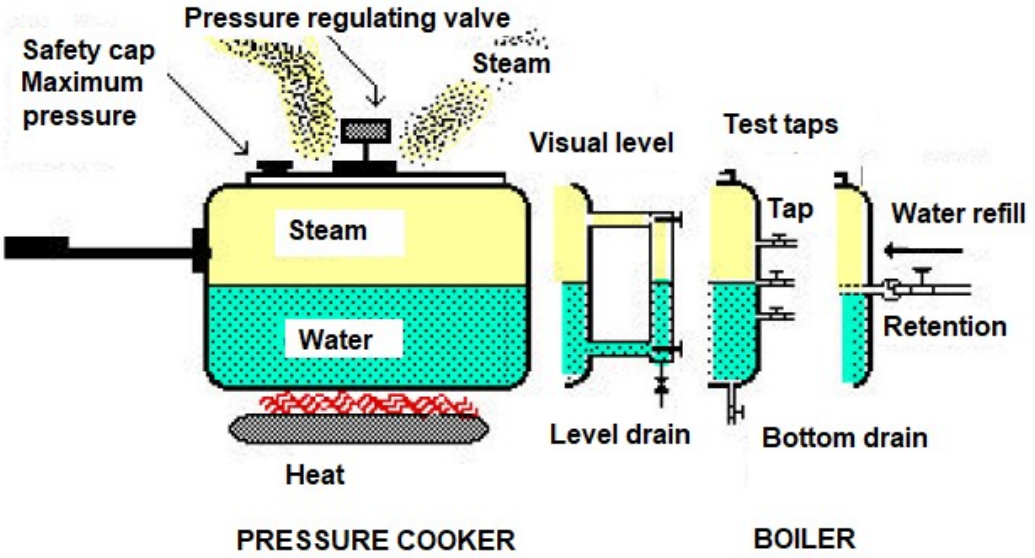
1- Its function is not to produce steam for consumption, as the amount of water is insufficient. If we were to use the steam, we would need to connect a pipe with a higher water pressure than the pressure inside the cooker, a valve to regulate the amount of water entering, and a level indicator to monitor the water level.

We all know that if the water runs out, the metal will "burn" due to contact with the fire (high temperatures), which is the most common cause of accidents involving boilers.

The sight glass (made of special glass) must have a protective mechanism in case it breaks and shatters, and connection valves (for when it breaks), good lighting, and a purge valve to remove any debris that might clog it (this debris is sludge formed by the precipitation of salts carried by the water).

Since the connections to the steam chamber and the water chamber of this tube can become blocked (or the tube can break while the boiler is running, or the boiler can lose its sight glass: for example, a high level where there is only water in the tube or a low level where there is only steam; in both cases, it is not possible to tell which situation is occurring at first glance.

Sometimes purging the level can reveal it, but it is not easy), therefore, there must be a system to easily check if the water level is within a certain range (covering the metal surface heated by the fires).



Three level test valves are installed. The top valve releases only steam, the bottom valve only water (and "flash" steam – water that evaporates due to lower pressure), and the middle valve releases steam depending on whether the water level is above or below it.

2- The steam pressure to be produced will not be controlled by releasing steam into the atmosphere, but by controlling the amount of fire.

For this, the combustion system (regardless of the fuel) must have a combustion quantity regulation system.

Normally, for liquid and gaseous fuels, we will regulate the amount of fuel and air entering the combustion chamber, either manually or automatically.

For solid fuels (firewood, coal, etc.), we will regulate the air (without air there is no combustion) manually or automatically (since the firewood or coal is in a significant quantity in the firebox, which

we cannot remove, although we can later decrease or increase its hourly rate).

3- We will see that the maximum amount of steam produced depends on the maximum amount of combustion, but this is limited by the surface area of the metal that transmits the heat.

If we want more steam, we must increase the "heating surface" (the metal surface exposed on one side to the heat of combustion and on the other side to contact with the water—or a mixture of water and steam).

To achieve this and to make better use of the heat, it became necessary to pass the "flues" (hot combustion gases) through the tubes, creating the "fire-tube" boiler.

Later, due to the need to work at higher pressures and with greater safety, the "water-tube" boiler was created. If we consider boilers from the perspective of their operating pressure, we can establish three arbitrary categories: low-pressure boilers, medium-pressure boilers, and high-pressure boilers.

This division is also standardized by various associations (standards), but we will divide it arbitrarily according to our understanding, based primarily on the pressure related to the quality of the water used (we will see later the importance of the water used with respect to operating pressure and boiler type), and we will specify which types of boilers fall within these pressure ranges:

- **Low-pressure boilers**: Up to 10 kg/cm² (142 PSI), fire-tube boilers predominate.

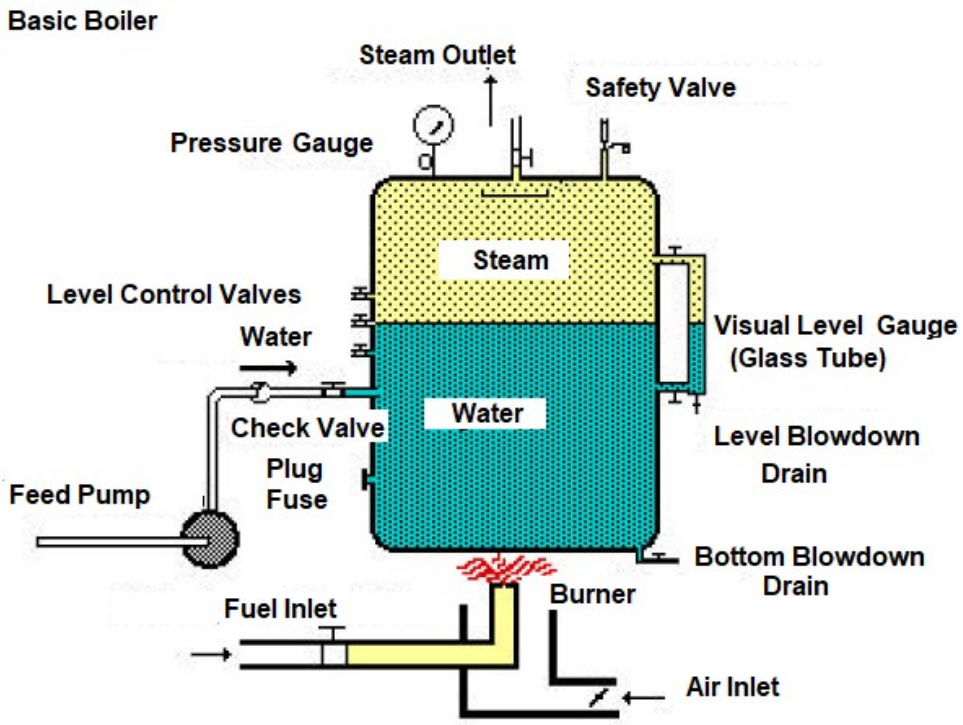
-**Medium-pressure boilers**: Up to 30 kg/cm² (427 PSI); above 20 kg/cm² (284 PSI), water-tube boilers predominate.

-**High-pressure boilers**: Above 30 kg/cm² (427 PSI), only water-tube boilers are available.

4- To function as a steam boiler, our basic boiler (the pressure cooker) must be fitted with a pressure gauge to measure the steam pressure (generally, the pressure should be kept constant).

This gauge will allow us to control the amount of combustion needed (without a pressure gauge, it's impossible to control a boiler; we'll see that each pressure corresponds to only one temperature when water and pure steam are in a closed container).

A steam outlet valve (to open and close the supply of steam for consumption), and a bottom blowdown valve (for removing sludge and dissolved salts that accumulate in the boiler water, resulting from the salts present in the incoming water and the chemicals used in its treatment).



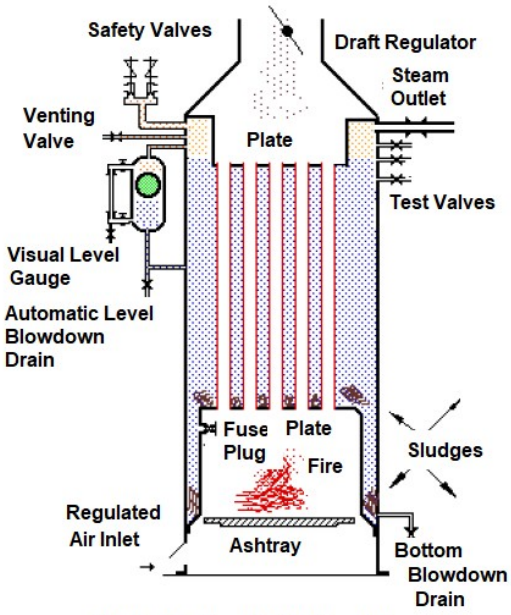
This boiler is missing other necessary, but not essential, elements, which we will see in the following topics.

To introduce this same water, we will need a water pump with sufficient pressure to overcome the boiler's internal pressure. (This pump must be connected to the boiler with a check valve, which allows water to enter the boiler when the supply is turned on, but prevents the boiler pressure from overcoming the pump pressure at any point if the pump pressure drops, or if the pump stops and water escapes from the boiler.)

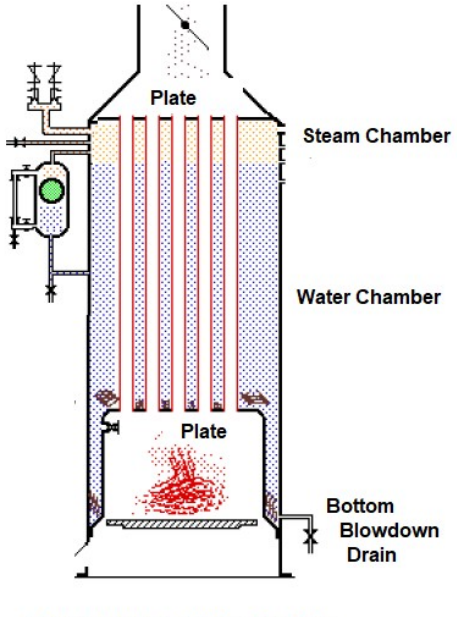
The pressure regulating valve will be called a safety valve (its function will be to release excess pressure if we cannot reduce the combustion rate in time).

There must be a "fusible plug" (so that it "melts" due to the heat and releases pressure if the boiler runs out of water or the water level drops below a certain limit, supposedly "capable of extinguishing the fire" with its steam release, or at least providing a warning that the low water level is occurring in order to stop combustion).

In the past, the plug was also used as a temperature limiter due to pressure rise, but the melting point became very uncertain, since the melting materials (tin and others, combined) changed their composition under operating conditions (temperature changes, exposure to the environment, etc.), altering their melting point.



Vertical Boiler with Wet Top Plate



Vertical Boiler with Dry Top Plate

Currently, the aim is to use pure materials that do not decompose, such as pure tin, whose sole function is to control the presence of water ("melting" due to the heat in case of water shortage).

For startup, when the boiler is cold, we must have an "atmospheric valve" to release the air from inside the boiler as it heats up (or to break the vacuum when emptying it). There will be a series of accessories, some necessary (but not essential) and others essential, such as those mentioned above.

Our "pressure cooker" will be transformed into a steam boiler by incorporating all these minimum necessary elements: Pressure gauge. Visual level control. Safety valves. Direct level control (valves). Fuse plug. Level and bottom drains. Feed pump and its control and check valves. Steam outlet valve.

Fuel and air controls, and other necessary or essential accessories according to the desired boiler design.

It is important to clarify that pressure not only controls the steam temperature but also defines the limit for controlling the stress the vessel must withstand (maximum working pressure limit).

This means that if we exceed the working pressure limit, we are running the risk that the pressure vessel or boiler may rupture and its expansion into atmospheric pressure will not only cause structural damage, but also thermal damage ("burns") and secondary effects, such as a second over-pressure on the walls of the enclosure and in turn the "bursting" of said enclosure (walls, ceilings, etc.).

SUMMARY:

This basic boiler operates by harnessing the heat produced by combustion. The amount of heat can be regulated according to need (maintaining working pressure) by adjusting the amount of fuel and air.

This heat is transferred to the water (a mixture of water and steam) through the metal, causing the water to vaporize, first by raising its temperature (sensible heat) and then by evaporating it (latent heat).

This steam is then forced by the generated pressure into the pipes where it will be consumed (condensed).

The amount of water entering through the feed must equal the amount of water that evaporates plus the amount that must be extracted through blowdown and other losses.

We have sufficient protections to maintain the pressure within a maximum limit and to maintain the appropriate water level. The fusible plug serves as a protection in case the water level drops too low and we are unable to extinguish the fire.